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AIRY, G. B,

Difference of Longitude between the
Observatories of Brussels and Greenwich

ON THE

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OBSERVATORIES OF BRUSSELS AND GREENWICH,

AS DETERMINED BY GALVANIC SIGNALS.

By G. B. AIRY, Esq.

ASTRONOMER ROYAL.

(*From the Memoirs of the Royal Astronomical Society, Vol. XXIV.*)

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PAPERS.

I. *On the Difference of Longitude between the Observatories of Brussels and Greenwich, as determined by Galvanic Signals.* By G. B. Airy, Esq. Astronomer Royal.

Read Nov. 10, 1854.

Section I.—*History and General Arrangements.*

The increasing importance of galvanic communication in the operations of observing astronomy, and the completion of the line of submarine telegraph from the South Foreland to Sangatte, induced me, in the winter of 1851, to solicit the sanction of the Lords Commissioners of the Admiralty for the establishment of a galvanic system at the Royal Observatory of Greenwich, and of wires connecting it with the principal telegraph-offices in London. Their Lordships were pleased immediately to grant the necessary authority; and the Directors and Officers of the South Eastern Railway Company, and of the Electric Telegraph Company, gave every assistance in their power. The wires were, in consequence, laid in the summer of 1852. Although (in consequence of a change in the relations of the telegraph companies) these wires were not used, as was at first contemplated, for communication with the Continent; yet their establishment was of great importance, as giving me communication with all parts of Britain, and as enabling me to make the proper arrangements for satisfactory use of galvanic communication by any system of wires. The first determinations of difference of longitude from Greenwich (which, as far as the galvanic operations were concerned, were perfectly satisfactory) were those of Cambridge and Edinburgh, in the summer of 1853, both which were made with these wires.

In the meantime, the Submarine and European Telegraph Company had laid another system of submarine wires from the South Foreland to Ostend, communicating by the Belgian telegraph wires immediately with Brussels. They had also laid a number of subterraneous wires from their office in Cornhill to the commencement of the submarine lines at the South Foreland. The subterraneous line passes by the side of the Dover Road across Blackheath, at a distance of less than half-a-mile from the Royal Observatory. Upon my making application to the Chairman and Directors of the Submarine and European Telegraph Company, permission was immediately given to me to connect a wire from the Royal Observatory with one of the Company's wires. It is proper that I should describe the way in which this connexion was effected, not only for explanation of the course pursued in the observations to be detailed below, but also for the purpose of showing the liberality with which the Company acceded to my views, and the trust which they have placed in me.

From the transit-room of the Royal Observatory, a copper wire, doubly covered with gutta percha, is carried along the garden walls till it reaches the great Blackheath avenue of Greenwich Park. It is there carried underground (without any protection) along the whole length of the avenue, and near the middle of its breadth, at the depth of 2 feet below the surface. On approaching the Park wall, it is turned aside to the west side of the gates, and is then carried upwards to an iron box in the wall, and there it terminates.

The course of the telegraph wires on Blackheath being known, the ground was opened till the workmen reached the wooden trough in which the wires are laid. They cut a hole in the side of the trough, took hold of one of the wires and cut it, and soldered fresh pieces of wire to the divided segments, and led them underground to the same iron box in the Park wall. From the mode in which the operation was performed, it was impossible at first to say which was the wire that had been taken; but, by the usual tests, it was afterwards proved to be one of the wires communicating with Paris. A turn-plate was then fixed in the iron box, containing 3 pieces of brass, with which, respectively, are connected the London segment of telegraph wire, the Paris segment of telegraph wire, and the Observatory wire; and on which are engraved the words, "London," "Paris," "Greenwich." Any two of these pieces of brass can be connected. In the ordinary use of the telegraph, the turn-plate is so placed, that "London" and "Paris" are connected, and the telegraph signals then pass without reference to the Observatory. But if "Greenwich" and "Paris" are connected, signals can pass directly between the Observatory and Paris. And if "Greenwich" and "London" are connected, signals can pass between the Observatory and London, or between the Observatory and any place with which London is connected.

In order, therefore, to establish a communication between the Royal Observatory and Brussels, it is necessary, by means of the turn-plate, to make the connexion "Greenwich—London," and then to rely on the kindness of the conductors of the telegraph office in Cornhill for making a temporary communication between the London end of the Paris wire and that of the Brussels wire, the connexions of these wires with the earth being first cut off.

To this description of the connexion with the telegraph line, I have only to add, that the key of the iron box is placed in my custody; a mark of confidence of which I am not insensible.

The interest with which M. ARAGO, and other members of the French Académie des Sciences, had, in 1851, urged the determination of their difference of longitude; and the priority of completion of the submarine telegraph to the French coast; had induced me to contemplate the investigation of our difference of longitude with Paris as the first use to be made of our connexion with the Submarine Company's wires; and, in the summer and autumn of 1853, negotiations for that purpose were in progress with the Bureau des Longitudes. These were interrupted by the illness of M. ARAGO, and other causes. I then considered myself at liberty to commence with the longitude of Brussels; and on my communicating with M. QUETELET, I found him most anxious to proceed with the enterprise. At the representation of M. QUETELET, and with the sanction of the Belgian government, a wire was laid from the telegraph office in the Station du Nord at Brussels to the Observatory, and the good offices of the Telegraph Company were assured for making the wire-connexions at the proper hour of the evening. A galvanic telegraph-needle was mounted in the Observatory in close proximity to the transit-clock, nearly as in the Greenwich Observatory.

The signals to be made were simple deviations of the needle, produced directly by the galvanic current through the long communicating wire; and the observation was to consist merely of careful observation and register of the clock-time of each deviation of the needle.

It was arranged that the observations should be divided into two series: that, in the first series, an observer from Brussels (M. Bouvy) should observe both the galvanic signals and the transits for correcting the transit-clock at Greenwich, while an observer from Greenwich (Mr. Dunkin) made the corresponding observations at Brussels: that this series should be continued till at least three evenings' observations, satisfactory in the determinations of clock-correction, as well as in the record of the signals, should be obtained: that the observers should then be reversed, and the second series be observed in the same manner. The signals were to occupy one hour in each evening, from 10^h to 11^h Brussels mean solar time ($9^h\ 43^m$ to $10^h\ 43^m$ Greenwich, nearly); each hour being divided into four quarters, the contacts of wires for completing galvanic circuit were to be made at Greenwich and with a Greenwich battery in the first and third quarters, and at Brussels with a Brussels battery in the second and fourth quarters (or *vice versâ*); and between the two sets of observations at each place, the poles of the battery were to be reversed.

It was laid down as indispensable that the persons who observed the signals should not make the contact by which the circuit is completed and the signals are given. The completion of the circuit produces similar movements of the needles at the two observatories, and the observers' attention was to be concentrated entirely on them. At Brussels, the circuits were completed by M. Quetelet, by the contact of two wires, in a distant part of the transit-room, out of sight of the observer. At Greenwich, the form of the apparatus admits of the contacts being made by two different methods: either by the American touch-piece upon the transit-circle (which was preferred, as being noiseless), or by a speaking-instrument; both these are in the transit-room, but the contacts were so made, usually by Mr. Henderson, that no inconvenience resulted from their proximity.

Batteries were lent to the Greenwich Observatory by the Electric Telegraph Company. The ordinary force employed consisted of eleven 12-cell batteries, sometimes augmented (I believe without any necessity) by several disposable batteries of the Royal Observatory. The force at Brussels was not so great. No injurious effect was produced by this disparity; as observations made at my request by LATIMER CLARK, Esq., on the velocity of transmission through 800 miles of subterraneous wire, have shown that, with forces varying in the proportion of 1 to 8, the time of transmission is sensibly the same.

The following was the routine of an evening's observation of signals in the first series. In the second series, everything was similar, except that Brussels commenced instead of Greenwich. By "warning-signals" are meant signals at intervals of 3^s nearly, intended only to be counted; by "observation-signals" are meant signals at intervals of 14^s or 15^s, intended to be accurately observed.

In the first quarter of hour,

Greenwich gave 4 warning-signals, as tokens of readiness. Brussels answered by 4 warning-signals.

Greenwich gave 2 warning-signals signifying "transits," and then gave warning-signals equal in number to the transits of stars observed on the last preceding evening after galvanic signals. If no transits had been observed, the 2 signals were omitted.

Greenwich gave observation-signals in groups of 7 to 10 in number, each group being preceded by a similar number of warning-signals.

In the second quarter of hour,

Brussels gave signals like those of Greenwich in the first quarter (omitting the 4 signals).

In the third quarter of hour,

Greenwich gave 2 warning-signals for "transits," and then gave warning-signals equal in number to the transits of stars observed this evening. If no transits were observed, the 2 were omitted.

Greenwich gave observation-signals in groups, with warning-signals as before, the poles of the battery being reversed.

On the day on which, in the opinion of the Greenwich observers, the operation might properly terminate, Greenwich gave 15 warning-signals.

In the fourth quarter of hour,

Brussels gave signals like those of Greenwich in the third quarter.

It is necessary now to explain the arrangements for the correction of the transit-clocks. They are the same which were first suggested by Professor Challis, in the operations for the longitude of Cambridge.

Two methods were used, called respectively Method A and Method B.

In Method A, transits of fundamental stars were used; their right ascensions being taken, for the reductions at both observatories, from the Greenwich Fundamental Catalogue. The stars employed were not necessarily the same at the two observatories.

For Method B, two lists of stars were prepared, one preceding and one following the signals. The stars' places were not supposed to be at all exact; but, before using them for correcting the clock, the lists of stars observed at the two observatories were compared, and all were rejected which were observed at only one observatory. In this manner the transits of strictly the same stars were compared, and the correctness of their assumed right ascensions was unimportant.

The determinations of the collimation-error, level-error, and azimuthal-error, of the transit-instruments, were referred to the judgment of the superintendents of the two observatories.

I think it probable that a course generally similar to that described above will be found convenient in any future operation of similar character. In the method of giving the signals, however, I have at this time (August 1854) made a great improvement. By means of an auxiliary clock, the circuit is automatically completed and the signal is given at every 15^s as shown by that clock. The approximate knowledge of the time of signal enables the observer to concentrate all his attention on the observation, and the difference between the rate of the auxiliary clock and the rate of the transit clock (which it is in the power of the superintendent to adjust) causes the signals to occur at different portions of the seconds shown by the transit-clock. In circumstances which permit the record of clock-seconds and observations or signals, by punctures produced by a galvanic magnet upon a revolving disk or barrel, or the transmission of transits by a galvanic wire, a simpler method may be employed.

I shall now give a brief journal of this operation.

1853. Nov. 24. M. Bouvy, Assistant of the Brussels Observatory, arrived at Greenwich; and about the same time, Mr. Dunkin, Assistant of the Greenwich Observatory, reached Brussels.

1853. Nov. 25. Signals were given on both sides, commencing the First Series. From an accidental contact in the Greenwich Transit Room, the Greenwich signals were not transmitted to Brussels, and the evening's work was rendered useless.

26. Good signals were interchanged; no transits were observed at Greenwich.

27. Good signals; no transits were observed at Brussels.

28. The signals were suspended; the Belgian Government requiring the use of the telegraph.

29. Good signals; no transits at Greenwich.

30. Good signals, slightly interrupted by a repair of the telegraph-wire; no transits at Greenwich.

Dec. 1. Good signals, and transits at both observatories: this is the first efficient evening.

2. Good signals, and transits at both observatories. The excessive dampness of the air had to this time usually prevented the gutta-percha supports from insulating the contact-apparatus on the transit-circle; and it had been necessary to detach it, and to use the speaking-instrument; but this day all was so dry (and continued so to the end), that the contact-apparatus could be used.

3. Good signals; no transits at Greenwich.

4. Good signals, and transits at both observatories. The 15 signals were given on both sides, and the First Series terminated.

5 and 6. M. Bouvy returned to Brussels, and Mr. Dunkin to Greenwich.

19. The Second Series was commenced. Good signals, but one transit only was observed at Greenwich.

20. A partial failure of signals, from want of connexion in the Brussels office. No transits at Greenwich.

21. Good signals, but no transits at Greenwich.

22. The signals were interrupted by some unknown accident on the telegraph line.

23. Good signals, no transits at Brussels.

24. Good signals, and transits at both observatories.

25. No signals were passed.

26. Good signals, no transits at Greenwich.

27. Good signals, no transits at Brussels.

28. Good signals, and transits at both observatories.

29. Good signals, and transits at both observatories.

30. Good signals, and transits at both observatories. The 15 signals were given on both sides, and the Second Series terminated.

I am bound to state that, throughout this protracted operation, not a single failure occurred in making the connexions of wires in the Cornhill office.

Section II.—*Comparison of Observations of the Galvanic Signals, by different Observers.*

As it was intended, by the interchange of observers, to eliminate the errors arising from personal equation, as well of signal-observation as of transit-observation, no particular effort was made to obtain a comparison of the various modes of observation. No efficient comparison of the two real observers (Messrs. Bouvy and Dunkin) could have been made without a most inconvenient extension of the operation.

The following comparisons were, however, incidentally made. It appears sufficient here, and in other parts of this record, to give the means and the ranges, without burdening the memoir with the whole detail of figures.

Comparisons of the Times of Signals as observed by M. Bouvy *and* Mr. Henderson. (The sign — denotes that the time written down by Mr. Henderson was less than that written by M. Bouvy.)

Nov. 26.	H—B, by mean of 69 signals	$-0^{s}\cdot12$
	Greatest value $+0^{s}\cdot5$, least $-0^{s}\cdot7$.	
Nov. 27.	Mean of 71 signals	$-0\ \cdot10$
	Greatest value $+0\ \cdot1$, least $-0\ \cdot4$.	
Nov. 29.	Mean of 74 signals	$-0\ \cdot14$
	Greatest value $+0\ \cdot1$, least $-0\ \cdot9$.	
Dec. 2.	Mean of 36 signals	$-0\ \cdot13$
	Greatest value $+0\ \cdot5$, least $-0\ \cdot6$.	
Dec. 3.	Mean of 41 signals	$-0\ \cdot33$
	Greatest value $+0\ \cdot5$, least $-0\ \cdot8$.	
Dec. 4.	Mean of 76 signals	$+0\ \cdot09$
	Greatest value $+0\ \cdot5$, least $-0\ \cdot5$.	

Comparisons of the Times of Signals as observed by M. Bouvy *and* Mr. Henry.

Dec. 3.	Henry—B., by mean of 159 signals	$-0^{s}\cdot26$
	Greatest value $+0^{s}\cdot9$, least $-0^{s}\cdot9$.	

SECTION III.—*Comparisons of the recorded Clock Times of Galvanic Signals observed at Brussels and Greenwich, which are not accompanied by Astronomical Observations.*

The signals which were not accompanied by observations of transits are useless for the determination of difference of longitude. They are, however, perfectly available for determining the time occupied by the passage of the galvanic current from Greenwich to Brussels, or *vice versâ*, as will appear from the following explanation of the method of treating them.

In the first series, the signals of the first quarter of each hour were given exclusively by Greenwich contact near the Greenwich battery. Let t be the time occupied by the passage of the current: then, during this first quarter, the times read from the Greenwich clock will not be increased from this cause, but the times read from the Brussels clock will be increased by t. The reading of the Brussels clock is (in consequence of its eastern longitude) usually greater than that of the Greenwich clock. Suppose that the excess, as unaffected by time of transmission, ought to be found $= E_1$, but that, as affected by time of transmission, it appears (on comparison of observations) to be e_1: then the comparisons of the observations of the first quarter of an hour give this equation,

$$E_1 + t = e_1$$

where E_1 and t are yet unknown.

In the second quarter of each hour, the signals were given exclusively by Brussels contact near the Brussels battery. In this case, the Brussels clock-readings were not increased, but the Greenwich clock-readings were increased by t, and therefore the excess of the Brussels clock-readings was diminished by t. Hence these comparisons gave

$$E_2 - t = e_2.$$

Similarly the third quarter gives

$$E_3 + t = e_3;$$

and the fourth quarter,

$$E_4 - t = e_4.$$

If the two clocks had no relative rate, the four numbers E_1, E_2, E_3, E_4, would be equal. As it is certain, however, that there was a relative rate, the only supposition that we can venture to make is, that the rate was uniform during the hour. We may also, in most cases, assume, that the mean of the signals in each quarter of hour corresponded (with sufficient approximation) to the middle of the quarter of hour. Let the relative rate for one quarter of hour be r: then the equations become

$$\begin{array}{lcl} E_1 \qquad\quad + t & = & e_1 \\ E_1 + \quad r - t & = & e_2 \\ E_1 + 2\,r + t & = & e_3 \\ E_1 + 3\,r - t & = & e_4 \end{array}$$

The easiest way of treating these equations is the following:

Subtract the double of the second equation from the sum of the first and third:

$$4\,t = e_1 + e_3 - 2\,e_2, \quad \text{or } t = \frac{e_1 + e_3 - 2e_2}{4}$$

Subtract the sum of the second and fourth equations from the double of the third:

$$4\,t = 2\,e_3 - e_2 - e_4, \quad \text{or } t = \frac{2\,e_3 - e_2 - e_4}{4}$$

The mean of these two determinations may probably be adopted as preferable to either of them alone.

In the second series, when the signals in the first and third quarters were given from Brussels, the process is the same, but the sign of t must be changed.

The following are the results of the individual days' observations:

First Series.

Nov. 26. Excess of readings of Brussels clock, omitting $17^{\text{m}}\ 50^{\text{s}}$.

First quarter, mean of 41 signals $2^{\text{s}}{\cdot}088$; greatest $2^{\text{s}}{\cdot}7$, least $1^{\text{s}}{\cdot}5$
Second quarter, mean of 37 signals $1{\cdot}776$; greatest $2{\cdot}1$, least $1{\cdot}4$
Third quarter, mean of 42 signals $2{\cdot}121$; greatest $2{\cdot}7$, least $1{\cdot}7$
Fourth quarter, mean of 35 signals $1{\cdot}911$; greatest $2{\cdot}5$, least $1{\cdot}6$

First determination of t	$0^{\text{s}}{\cdot}164$
Second	$0{\cdot}139$
Mean	$0{\cdot}152$

Nov. 27. Excess of reading of Brussels clock, omitting $17^{m}\ 50^{s}$.

First quarter, (three excesses increased each by 1^{s}.)

mean of 29 signals $0\overset{s}{\cdot}859$; greatest $1\overset{s}{\cdot}2$, least $0\overset{s}{\cdot}4$

Second quarter, mean of 35 signals 0·711; greatest 1·7, least 0·3

(1·7 is probably an error. The next is 1·0)

Third quarter, (one excess diminished by 1^{s})

mean of 40 signals 1·015; greatest 1·5, least 0·7

Fourth quarter, (one 0·2 rejected)

mean of 39 signals 0·818: greatest 1·1, least 0·3

First determination of *t*	$0\overset{s}{\cdot}113$
Second	0·125
Mean	0·119

Nov. 29. Excess of reading of Brussels clock, omitting $17^{m}\ 40^{s}$.

First quarter, mean of 39 signals $9\overset{s}{\cdot}200$; greatest $9\overset{s}{\cdot}7$, least $8\overset{s}{\cdot}5$

Second quarter, mean of 41 signals 8·895; greatest 9·1, least 8·6

Third quarter, (one 10·4 rejected)

mean of 39 signals 9·190; greatest 9·8, least 8·8

Fourth quarter, mean of 40 signals 8·970; greatest 9·2, least 8·1

First determination of *t*	$0\overset{s}{\cdot}150$
Second	0·128
Mean	0·139

Nov. 30. Excess of reading of Brussels clock, omitting $17^{m}\ 40^{s}$.

First quarter, few signals.

Second quarter, (one of $7\overset{s}{\cdot}3$ rejected).

mean of 27 signals $8\overset{s}{\cdot}489$; greatest $9\overset{s}{\cdot}0$, least $7\overset{s}{\cdot}8$

Third quarter, (one of 7·4 rejected).

mean of 41 signals 8·622; greatest 9·4, least 8·2

Fourth quarter, mean of 46 signals 8·509; greatest 9·1, least 8·1

Second determination of *t* $0^{s}{\cdot}061$

Dec. 3. Excess of reading of Brussels clock, omitting $17^{m}\ 40^{s}$.

First quarter, mean of 40 signals $3\overset{s}{\cdot}713$; greatest $4\overset{s}{\cdot}3$, least $3\overset{s}{\cdot}3$

Second quarter, mean of 40 signals 3·547; greatest 4·2, least 2·9

Third quarter, mean of 40 signals 3·677; greatest 4·4, least 3·2

Fourth quarter, mean of 41 signals 3·359; greatest 4·3, least 2·5

First determination of *t*	$0\overset{s}{\cdot}074$
Second	0·112
Mean	0·093

Second Series.

Dec. 19. Excess of reading of Brussels clock, omitting $17^{\mathrm{m}}\ 30^{\mathrm{s}}$.

First quarter, mean of 41 signals $\overset{\mathrm{s}}{10}{\cdot}298$; greatest $\overset{\mathrm{s}}{10}{\cdot}7$, least $\overset{\mathrm{s}}{9}{\cdot}8$
Second quarter, mean of 42 signals 10·564 ; greatest 11·4, least 10·0
Third quarter, mean of 42 signals 10·467 ; greatest 10·7, least 9·8
Fourth quarter, mean of 45 signals 10·627 ; greatest 11·5, least 10·1

First determination of *t* $\overset{\mathrm{s}}{0}{\cdot}090$
Second 0·065
Mean 0·078

Dec. 20. Excess of reading of Brussels clock, omitting $17^{\mathrm{m}}\ 30^{\mathrm{s}}$.

First quarter, few signals received.
Second quarter, mean of 38 signals $\overset{\mathrm{s}}{10}{\cdot}245$; greatest $\overset{\mathrm{s}}{10}{\cdot}6$, least $\overset{\mathrm{s}}{9}{\cdot}8$
Third quarter, mean of 45 signals 9·922 ; greatest 10·7, least 9·5
Fourth quarter, mean of 45 signals 10·142 ; greatest 10·7, least 9·7

Second determination of *t* $0^{\mathrm{s}}{\cdot}136$

Dec. 21. Excess of reading of Brussels clock, omitting $17^{\mathrm{m}}\ 30^{\mathrm{s}}$.

First quarter, mean of 48 signals $\overset{\mathrm{s}}{9}{\cdot}248$; greatest $\overset{\mathrm{s}}{9}{\cdot}6$, least $\overset{\mathrm{s}}{8}{\cdot}6$
Second quarter, mean of 42 signals 9·281 ; greatest 10·4, least 8·7
Third quarter, mean of 40 signals 9·087 ; greatest 9·5, least 8·5
Fourth quarter, mean of 46 signals 9·280 ; greatest 9·7, least 8·8

First determination of *t* $\overset{\mathrm{s}}{0}{\cdot}057$
Second 0·097
Mean 0·077

Dec. 23. Excess of reading of Brussels clock, omitting $17^{\mathrm{m}}\ 30^{\mathrm{s}}$.

First quarter, mean of 38 signals $\overset{\mathrm{s}}{7}{\cdot}684$; greatest $\overset{\mathrm{s}}{8}{\cdot}0$, least $\overset{\mathrm{s}}{7}{\cdot}3$
Second quarter, mean of 45 signals 7·844; greatest 8·4, least 7·3
Third quarter, mean of 45 signals 7·544; greatest 7·8, least 7·3
Fourth quarter, mean of 51 signals 7·841; greatest 8·2, least 7·4

First determination of *t* $\overset{\mathrm{s}}{0}{\cdot}115$
Second 0·150
Mean 0·132

Dec. 26. Excess of reading of Brussels clock, omitting $17^{\mathrm{m}}\ 30^{\mathrm{s}}$.

First quarter, mean of 42 signals 6^{s}·633; greatest 6^{s}·9, least 6^{s}·3
Second quarter, mean of 50 signals 6·852; greatest 7·3, least 6·4
Third quarter, mean of 46 signals 6·585; greatest 7·0, least 6·2
Fourth quarter, mean of 50 signals 6·836; greatest 7·3, least 6·3

First determination of *t*	0^{s}·122
Second	0·129
Mean	0·126

Dec. 27. Excess of reading of Brussels clock, omitting $17^{\mathrm{m}}\ 30^{\mathrm{s}}$.

First quarter, mean of 42 signals 5^{s}·500; greatest 5^{s}·8, least 4^{s}·8
Second quarter, mean of 47 signals 5·749; greatest 6·3, least 5·3
Third quarter, mean of 44 signals 5·577; greatest 6·0, least 5·1
Fourth quarter, mean of 48 signals 5·758; greatest 6·1, least 5·4

First determination of *t*	0^{s}·105
Second	0·088
Mean	0·097

The mean results will be collected, with those obtained on the days available for determination of longitude, in a following section.

SECTION IV.—*Authorities for the Instrumental Errors and Clock Errors on the Days which are available for Determination of Difference of Longitude.*

It does not appear necessary to give here the mass of figures on which, directly or indirectly, the determination of true sidereal time of signals at each observatory rests. But it appears desirable that the reader should be fully in possession of the methods used for determining the co-efficients of instrumental and clock correction, and that so much of the numerical values of these co-efficients should be given as will enable him to judge of the stability of the instruments and the general trustworthiness of results.

The corrections of the transit-instruments were usually determined for groups of days, and it will be convenient to state these and the authorities for them, collectively, in the first place. The elements of clock correction will be given afterwards, separately for each day.

At Brussels, the error of collimation of the transit-instrument was determined from transits of three fundamental stars, observed without reversion of the instrument, and compared with tabular places. The special determinations are as follows:—

1853, Nov. 18,	by β Ceti, Polaris, η U. Maj. S.P.	−4″·547
18–19,	by β Ceti, η U. Maj. S.P., η U. Maj.	−4·087
18,	by β Ceti, Polaris S.P., Polaris	−3·09
22,	by α Piscis Australis, γ U. Maj. S.P., α Cassiopeiæ	−3·686

The mean −3″·853 is adopted for the observations from Nov. 24 to Dec. 4.

1853, Dec. 20,	by Polaris, η U. Maj. S.P., β Ceti	−10″·823
20,	by α Persei, γ U. Maj. S.P., β Ceti	−10·040
22,	by Polaris, η U. Maj. S.P., β Ceti	− 6·909
22,	by α Persei, η U. Maj. S.P., β Ceti	− 7·504
28,	by Polaris, η U. Maj. S.P., γ Eridani	− 9·189
28,	by α Persei, η U. Maj. S.P., γ Eridani	−10·581
29,	by Polaris, η U. Maj. S.P., γ Eridani	− 9·940
29,	by α Persei, η U. Maj. S.P., γ Eridani	−10·390

The mean −9″·422 is adopted for the observations from Dec. 24 to Dec. 30.

The inclination of the axis of revolution was found by means of a small level attached to the transit-instrument. The results were as follows:—

1853, Nov. 25	1″·13
26	0·60
27	3·94
30	0·49
Dec. 2	5·06
6	3·24

The mean 2″·41 was adopted for the First Series.

Dec. 16	2″·67
19	2·39
26	3·02
29	3·73

From these, the following were inferred by interpolation, and were adopted for the Second Series:—

	″
Dec. 22	2·66
24	2·84
28	3·50
29	3·73
30	3·97

The azimuthal errors were found by observations of *Polaris*, and are as follows:—

		″	
Nov. 24,	from Polaris S.P. and β Aquarii	5·21,	employed to Dec. 2.
Dec. 1,	from Polaris S.P. and η Boötis	5·02,	
2,	from Polaris S.P. and η Boötis	5·59,	employed for Dec. 3.
3,	from Polaris S.P. and α Virginis	6·02,	employed for Dec. 4.
22,	from Polaris and β Ceti	15·75,	employed on Dec. 22 and 24.
28,	from Polaris and γ Eridani	14·10,	employed on Dec. 28.
29,	from Polaris and γ Eridani	16·80,	employed on Dec. 29 and 30.

The following are the daily rates of the transit clock:—

			s
Nov. 24	to	Nov. 25	+0·408
25	to	26	+0·040
26	to	29	+0·346
29	to	30	−0·123
30	to	Dec. 1	+0·966
Dec. 1	to	2	+1·000
2	to	3	+1·028
3	to	4	+1·082
19	to	20	+0·772
20	to	22	+1·266
22	to	24	+1·260
22	to	28	+0·97
24	to	28	+0·825
28	to	29	+0·819
29	to	30	+0·573

At Greenwich the line of collimation of the transit-circle was determined by the aid of two fixed collimators, one on the north side and one on the south side. The instrument is raised every week, in order that one of these collimators may be enabled to view the other, and that the images of their wires may be placed in coincidence; and every day the two collimators, considered as opposite marks, are observed with the transit-circle for determination of its line of collimation.

The wire of the north collimator being fixed, and that of the south collimator adjustible by a micrometer of which one revolution = 32″·29; the readings of the micrometer at coincidence were found to be as follows:—

	r
1853, Nov. 21	0·554
28	·577
Dec. 5	·561
12	·558
19	·617
28	·621
1854, Jan. 2	·644

The readings of the transit-circle micrometer, of which one revolution = 14″·78, for the line of collimation of the transit-circle, were found (by observation of the two collimators when the micrometer of the south collimator was adjusted to the reading above given), to be as follows:—

	r	
1853, Nov. 28	31·413	The mean ·437 is adopted from Nov. 27 to Dec. 3
29	·440	
30	·457	
Dec. 1	·455	
2	·446	
3	·410	
5	·421	The mean ·412 is adopted from Dec. 4 to Dec. 10
6	·405	
7	·431	
8	·409	
9	·416	
10	·392	
19	·414	The mean ·429 is adopted from Dec. 18 to Dec. 24
20	·422	
21	·442	
22	·399	
23	·444	
24	·453	
27	·402	The mean ·413 is adopted from Dec. 25 to Dec. 31
28	·415	
29	·423	
30	·409	
31	·418	

The adopted readings for line of collimation being compared with the readings for the position of the wire in daily use, the error of collimation was found.

The error of inclination of the axis of revolution was found by comparing the reading of the transit-circle micrometer for the line of collimation with the reading of the same micrometer for coincidence of the direct and reflected images of the wire. The errors found were as follows:—

	″	
Nov. 30	+0·31	Mean +0″·25 adopted
Dec. 1	+0·19	
2	+1·54	Mean +1″·62 adopted
3	+1·69	
5	+0·78	Mean +0″·82 adopted from Dec. 4 to Dec. 10
6	+0·92	
7	+0·62	
8	+0·87	
9	+0·84	
10	+0·90	
19	+0·86	Mean +0″·57 adopted from Dec. 18 to Dec. 24
20	+0·47	
21	+0·47	
22	+1·04	
23	+0·33	
24	+0·22	
27	+1·27	Mean +1″·06 adopted from Dec. 25 to Dec. 31
28	+1·00	
29	+1·27	
30	+1·34	
31	+0·43	

The azimuthal error was found by first determining, on days which admitted of observations of *Polaris* above and below the pole, the azimuth of the transit-circle; secondly, using this azimuth in conjunction with observations of the north collimator, to determine the azimuth of the north collimator; thirdly, using the adopted azimuth of the north collimator and the daily references of the transit-circle to the north collimator, for determination of the azimuth of the transit-circle. The principal numbers here employed are the following:—

	″
Nov. 21, by observations of Polaris S.P. and Polaris, the western azimuth of the north collimator was found to be	−3·94
Dec. 2, by Polaris S.P. and Polaris	−2·93

The mean −3″·44 was adopted from Nov. 28 to Dec. 10.

Dec. 28 and 29, by Polaris S.P. and Polaris	−7·05 −6·89
Dec. 30 and 31, by Polaris, Polaris S.P., and Polaris	−6·39 −6·77

The mean −6″·78 was adopted from Dec. 19 to Dec. 31.

With these places of the north collimator, the azimuthal error of the transit circle was found as follows:—

	″	
Nov. 28	−3·07	The mean −2″·97 was used from Nov. 27 to Dec. 3
29	−3·31	
30	−3·47	
Dec. 1	−2·45	
2	−2·94	
3	−2·58	

Dec. 5	−3·66	The mean −3″·60 was adopted from Dec. 4 to Dec. 10
6	−3·72	
7	−3·72	
8	−3·51	
9	−3·54	
10	−3·44	

Dec. 19	−7·56	The mean −8″·04 was adopted from Dec. 18 to Dec. 24
20	−7·88	
21	−8·09	
23	−8·33	
24	−8·32	

Dec. 27	−8·00	The mean −8″·54 was adopted from Dec. 25 to Dec. 31
28	−8·39	
29	−8·56	
30	−9·06	
31	−8·67	

The following are the daily rates of the transit clock :—

		s
Nov. 23	to Nov. 25	−0·71
25	to 27	−0·59
27	to 28	−0·80
28	to Dec. 1	−0·60
Dec. 1	to 2	−0·62
2	to 4	−0·78
4	to 8	−0·56

(After an alteration of the clock adjustment.)

		s
Dec. 16	to Dec. 19	+0·47
19	to 22	+0·43
22	to 23	+0·26
23	to 24	+0·57
24	to 25	+0·45
25	to 27	+0·15
27	to 28	+0·21
28	to 29	+0·37
29	to 30	+0·37
30	to Jan. 1	+0·46

The determinations of clock error, on the days which are available for longitude, rested on the observations of the following stars :—

1853, December 1.

For Method A :

At Brussels : γ Aquilæ, α Aquilæ, β Aquarii, ε Pegasi, α Aquarii, α Andromedæ, γ Pegasi, β Ceti, θ Ceti, Aldebaran.

At Greenwich : α Lyræ, γ Aquilæ, α Aquilæ, β Aquilæ, θ Aquilæ, ζ Cygni, α Equulei, β Aquarii, ξ Aquarii, ε Pegasi, δ Capricorni, μ Andromedæ, ε Piscium, θ Ceti, η Piscium, ν Piscium, β Arietis, α Arietis, η Tauri, ε Tauri, Aldebaran.

For Method B :

γ Aquilæ, α Aquilæ, β Aquarii, ε Pegasi, ε Piscium, *e* Piscium, 40 Ceti, θ Ceti, η Piscium, π Piscium, ο Piscium, λ Tauri, Piazzi iii. 254, γ Tauri, ε Tauri, Aldebaran.

1853, December 2.

For Method A :

At Brussels : γ Aquilæ, α Aquilæ, β Aquilæ, ζ Cygni, β Aquarii, ε Pegasi, α Aquarii, α Andromedæ, γ Pegasi, β Ceti, θ Ceti, α Arietis, Aldebaran.

At Greenwich : α Coronæ, α Serpentis, β Ophiuchi, μ Herculis, α Lyræ, ε Aquilæ, ζ Aquilæ, α Vulpeculæ, γ Aquilæ, α Aquilæ, β Aquilæ, ε Piscium, θ Ceti, η Piscium, β Arietis, α Arietis.

For Method B :

γ Aquilæ, α Aquilæ, β Aquilæ, ε Piscium, *e* Piscium, 40 Ceti, θ Ceti, η Piscium, π Piscium, ο Piscium, α Arietis.

1853, December 4.

For Method A:

At Brussels: γ Aquilæ, α Aquilæ, β Aquilæ, α^2 Capricorni, ζ Cygni, β Aquarii, ε Pegasi, α Aquarii, γ Pegasi, θ Ceti, α Arietis, Aldebaran.

At Greenwich: α Andromedæ, ε Piscium, ν Piscium.

For Method B, there are no stars on this day.

1853, December 24.

For Method A:

At Brussels: α Arietis, α Ceti, γ Eridani, β Tauri, δ Orionis, α Leporis, ε Orionis, α Orionis.

At Greenwich: ο Tauri, η Tauri, γ Eridani, Rigel, β Tauri, δ Orionis, α Leporis, ε Orionis, α Orionis.

For Method B:

ξ Tauri, *f* Tauri, γ Eridani, β Tauri, δ Orionis, α Leporis, ε Orionis, *d* Orionis, 129 Tauri, 136 Tauri, α Orionis, 1 Geminorum.

1853, December 28.

For Method A:

At Brussels: θ Ceti, α Arietis, γ Ceti, α Ceti, η Tauri, γ Eridani, Aldebaran, α Orionis, μ Geminorum, Sirius, δ Geminorum.

At Greenwich: α Ceti, η Tauri, γ Eridani, β Tauri, δ Orionis, α Leporis, ε Orionis, α Orionis.

For Method B:

ε Arietis, α Ceti, δ Arietis, ζ Arietis, 64 Arietis, ξ Tauri, 12 Tauri, η Tauri, γ Eridani, *d* Orionis, 129 Tauri, 136 Tauri, α Orionis, 1 Geminorum.

1853, December 29.

For Method A:

At Brussels: γ Aquilæ, α Aquilæ, ζ Cygni, ε Pegasi, α Aquarii, θ Ceti, α Arietis, γ Ceti, α Ceti, η Tauri, γ Eridani, Aldebaran, α Orionis.

At Greenwich: ν Piscium, β Arietis, α Arietis, 67 Ceti, ξ^2 Ceti, γ Ceti, α Ceti, η Tauri, γ Eridani, β Tauri, δ Orionis, α Leporis, ε Orionis, α Orionis.

For Method B:

β Arietis, α Arietis, γ Ceti, σ Arietis, ε Arietis, α Ceti, δ Arietis, ζ Arietis, 64 Arietis, ξ Tauri, *f* Tauri, 12 Tauri, η Tauri, γ Eridani, 129 Tauri, 136 Tauri, α Orionis.

1853, December 30.

For Method A:

At Brussels: Aldebaran, α Orionis, μ Geminorum, Sirius.

At Greenwich: θ Ceti, η Piscium, ν Piscium, β Arietis, α Arietis, 67 Ceti, ξ^2 Ceti, γ Ceti, α Ceti, η Tauri, γ Eridani, δ Orionis, α Leporis, ε Orionis, α Orionis.

For Method B, there are no stars on this day.

The mean right ascensions of the stars used in Method A are given in the Fundamental Catalogue printed in the Introduction to the Greenwich Observations, 1853.

SECTION V.—*Comparisons of the Sidereal Times of Galvanic Signals observed at Brussels and Greenwich, on the days which are available for the Determination of Difference of Longitude.*

The observed transits were corrected numerically for the effects of the instrumental errors, of which the elements are given in the last section; the clock-errors were obtained by comparing the corrected transits with the tabular places of the stars specified in the last section; and these clock-errors, duly reduced to the time of signal-observation, were applied to the recorded clock-times of signals. The difference of these at the two observatories gives the apparent difference of longitude. The results for difference of longitude in the separate quarters of hour are treated in the same manner as the simple clock-comparisons in Section III., in order to obtain from them the time occupied by the galvanic current in passing between Brussels and Greenwich. For the difference of longitude (still subject to the effects of personal equation) it is necessary to take the mean of the four separate results.

The following are the numbers obtained on each day. The numbers first exhibited are those obtained by Method A; but the mean result by Method B is subjoined:—

First Series.

1853, December 1.

First quarter of hour,	mean of 35 signals	$17^{\mathrm{m}}\ 29^{\mathrm{s}}{\cdot}319$;	greatest $29^{\mathrm{s}}{\cdot}91$,	least $28^{\mathrm{s}}{\cdot}41$
Second quarter,	mean of 35 signals	17 29·106;	greatest 29·54,	least 28·73
Third quarter,	mean of 38 signals	17 29·378;	greatest 29·85,	least 28·85
Fourth quarter,	mean of 36 signals	17 29·203;	greatest 29·57,	least 28·46

First determination of *t*	$0^{\mathrm{s}}{\cdot}122$
Second	0·112
Mean	0·117

Difference of longitude $17^{\mathrm{m}}\ 29^{\mathrm{s}}{\cdot}252$ by Method A
17 29·282 by Method B

1853, December 2.

First quarter of hour, mean of 36 signals $17^{m}\ 29^{s}{\cdot}414$; greatest $29^{s}{\cdot}95$, least $29^{s}{\cdot}04$
Second quarter (one of 26·15 omitted),
mean of 38 signals 17 29·112; greatest 29·67, least 28·56
Third quarter, mean of 35 signals 17 29·443; greatest 30·18, least 28·48
Fourth quarter, mean of 39 signals 17 29·144; greatest 29·50, least 28·80

First determination of *t* $0^{s}{\cdot}159$
Second 0·157
Mean 0·158

Difference of longitude $17^{m}\ 29^{s}{\cdot}278$ by Method A
17 29·398 by Method B

1853, December 4.

First quarter of hour, mean of 40 signals $17^{m}\ 29^{s}{\cdot}194$; greatest $29^{s}{\cdot}73$, least $28^{s}{\cdot}83$
Second quarter, mean of 39 signals 17 29·222; greatest 29·55, least 28·35
Third quarter, mean of 38 signals 17 29·152; greatest 29·67, least 28·67
Fourth quarter, mean of 37 signals 17 29·384; greatest 29·79, least 28·79

First determination of *t* $-0^{s}{\cdot}024$
Second −0·076
Mean −0·050

(I can form no conjecture of the cause which occasioned later observation of the signals, in the immediate vicinity of the battery and the place of completing the circuit, than at the distant station, unless one of the clocks were subject to some irregularity of short duration, which does not show itself in the daily rates.)

Difference of longitude $17^{m}\ 29^{s}{\cdot}238$ by Method A
No determination by Method B

Second Series.

1853, December 24.

First quarter of hour, mean of 39 signals $17^{m}\ 28^{s}{\cdot}421$; greatest $28^{s}{\cdot}75$, least $28^{s}{\cdot}24$
Second quarter (one of 27·05 and one of 27·15 rejected),
mean of 44 signals 17 28·688; greatest 29·06, least 28·05
Third quarter, mean of 40 signals 17 28·392; greatest 28·85, least 28·15
Fourth quarter, mean of 38 signals 17 28·868; greatest 29·27, least 28·36

First determination of *t* $0^{s}{\cdot}141$
Second 0·193
Mean 0·167

Difference of longitude $17^{m}\ 28^{s}{\cdot}592$ by Method A
17 28·522 by Method B

1853, December 28.

First quarter of hour, mean of 44 signals 17$^{\text{m}}$ 28$^{\text{s}}$·450; greatest 28$^{\text{s}}$·87, least 28$^{\text{s}}$·18
Second quarter (one of 27·58 omitted),
mean of 45 signals 17 28·535; greatest 28·97, least 28·27
Third quarter (one of 29·38 omitted),
mean of 41 signals 17 28·391; greatest 28·68, least 28·18
Fourth quarter, mean of 44 signals 17 28·809; greatest 29·20, least 28·19

First determination of *t*	0$^{\text{s}}$·057
Second	0·141
Mean	0·099

Difference of longitude 17$^{\text{m}}$ 28$^{\text{s}}$·546 by Method A
17 28·556 by Method B

1853, December 29.

First quarter of hour, mean of 40 signals 17$^{\text{m}}$ 28$^{\text{s}}$·241; greatest 28$^{\text{s}}$·72, least 27$^{\text{s}}$·72
Second quarter, mean of 44 signals 17 28·555; greatest 28·92, least 28·13
Third quarter (one of 27·03 omitted),
mean of 38 signals 17 28·289; greatest 28·72, least 27·83
Fourth quarter, mean of 43 signals 17 28·553; greatest 28·84, least 27·63

First determination of *t*	0$^{\text{s}}$·145
Second	0·133
Mean	0·139

Difference of longitude 17$^{\text{m}}$ 28$^{\text{s}}$·410 by Method A
17 28·350 by Method B

1853, December 30.

First quarter of hour (one of 27·12 omitted),
mean of 39 signals 17$^{\text{m}}$ 28$^{\text{s}}$·411; greatest 29$^{\text{s}}$·11, least 28$^{\text{s}}$·01
Second quarter, mean of 39 signals 17 28·707; greatest 29·51, least 28·21
Third quarter, mean of 40 signals 17 28·562; greatest 29·02, least 28·01
Fourth quarter, mean of 40 signals 17 28·740; greatest 29·01, least 28·21

First determination of *t*	0$^{\text{s}}$·110
Second	0·081
Mean	0·096

Difference of longitude 17$^{\text{m}}$ 28$^{\text{s}}$·605 by Method A

No determination by Method B

Section VI.—*Abstract of the Results for the Time occupied by the Passage of the Galvanic Current, and for the Difference of Longitude.*

Combining all the results for the time occupied by the passage of the galvanic current, with the exception only of those of November 30 and December 20, which rest upon an insufficient number of signals, we have the following:—

Time apparently occupied by the Passage of the Galvanic Current between Brussels and Greenwich.

	s
1853, November 26	0·152
27	0·119
29	0·139
December 1	0·117
2	0·158
3	0·093
4	−0·050
19	0·078
21	0·077
23	0·132
24	0·167
26	0·126
27	0·097
28	0·099
29	0·139
30	0·096
Mean	0·109

This result rests upon 2616 observations. On these numbers I have to remark:—

1. There is no reason for rejecting the anomalous result of December 4. There is certainly no important error in the numerical calculations; and the observation, so far as the observers are aware, was conducted in the same

manner as on other days. The anomaly arises probably from some irregularity in one or both of the clocks, and its effects may be supposed to be balanced (as well as can be expected in other cases where the causes of irregularity are unknown) by the action of similar irregularities upon other days, acting in the opposite direction. The result of December 4 is fully entitled to enter into the formation of the mean with the same weight as each of the others. The discordance, however, tends to throw doubt upon the accuracy of the general mean, as representing with certainty the physical element sought.

2. The result $0^s \cdot 109$ may arise from the sum of two quantities. First, the time really occupied by the passage of the galvanic pulse. Secondly, the comparative slowness of perception of the observer at the distant station, arising from the more languid motion of the needle. But, having been fully able to appreciate the attention with which the observers watched the needle, and the intentness with which their energies were directed to seize its first movements; remarking also that, in consequence of the admirable insulation of the telegraph wires, the difference in the intensities of the current at the near and distant stations is very small, I am disposed to think that the number $0^s \cdot 109$ represents almost purely the time employed by the transit of the galvanic current.

3. The telegraphic distance between Brussels and Greenwich is about 270 miles. If the velocity of the current were uniform, the value obtained from these experiments would be little more than 2500 miles per second, or not more than one-seventh of that obtained by several American investigators. It is, however, to be remarked that from Greenwich to London, and thence to Ostend, the whole of the line is subterraneous or subaqueous; and that unpublished experiments by Mr. LATIMER CLARK (which, by the kind permission of that gentleman, I have myself witnessed), show that the velocity in such wires is not greater than 800 or 1000 miles per second. It appears, therefore, extremely probable that the retardation which we have discovered belongs almost entirely to the subterranean and submarine portion of the line; and that the retardation between Ostend and Brussels is practically insensible.

The results of different days for the difference of longitude are the following:—

First Series : M. Bouvy observing transits and signals at Greenwich,
and Mr. Dunkin at Brussels.

	Method A.	Method B.
	m s	m s
1853, December 1	17 29·252	17 29·282
2	17 29·278	17 29·398
4	17 29·238	
Mean	17 29·256	17 29·340

Second Series : M. Bouvy observing transits and signals at Brussels,
and Mr. Dunkin at Greenwich.

	m s	m s
1853, December 24	17 28·592	17 28·522
28	17 28·546	17 28·556
29	17 28·410	17 28·350
30	17 28·605	
Mean	17 28·538	17 28·476
Mean of the two Series	17 28·897	17 28·908

The whole number of signals on which these determinations rest is 1104.

The last result, or $17^{\mathrm{m}}\ 28^{\mathrm{s}}\cdot 9$, is indisputably the best that can be given at the present time for the difference of longitude of the two observatories. The difference, however, of the results given by the two series, $0^{\mathrm{s}}\cdot 791$, is somewhat striking. If it be attributed entirely to personal equation, it implies, either that M. Bouvy registers signals earlier by $0^{\mathrm{s}}\cdot 4$ than Mr. Dunkin would do in the same circumstances, their registers of transits of stars being identical; or that M. Bouvy registers transits later by $0^{\mathrm{s}}\cdot 4$ than Mr. Dunkin would do, their registers of signals being identical; or that M. Bouvy registers signals somewhat earlier and transits somewhat later, the sum of the two discordances amounting to $0^{\mathrm{s}}\cdot 4$. Neither of these explanations is impossible; and the second is supported by the remark which M. Quetelet has communicated to me, that M. Bouvy registers transits later by $0^{\mathrm{s}}\cdot 3$ or $0^{\mathrm{s}}\cdot 4$ than M. Quetelet does, while there is no sensible difference between their modes of observing signals. The first suggested explanation is not supported by the observations recorded in Section II.

The only remaining explanation of the difference of results of the two series, which appears possible, is, an error in the evaluation, in one or both series, of the instrumental errors. I have endeavoured to give all the means for decision on this point, and must leave it to the judgment of the reader.

When the American* method of recording transits by galvanic puncture upon a revolving plate or barrel shall be more extensively introduced into Europe, I think it probable that operations equal in value to that described in this paper may be effected in a shorter time. But even with the signals of the telegraph needle, repeated for a few days, the accidental errors of signal-observation may be considered as practically eliminated; and those of transit-observation will also sensibly vanish. The only remaining sources of error are,—the personal equations,—and the inaccuracy of instrumental adjustments; the former may be eliminated by interchange of observers; but, for the latter, only the most careful attention to the principles and the practice of the methods employed will suffice.

G. B. AIRY.

Royal Observatory, Greenwich,
1854, *September* 5.

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* I use this term as implying that the method in question was practically introduced and extensively applied in America before it was employed in any other country. I know not by whom or where the method was first proposed.

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